US009153452B2

(12) **United States Patent**
Liu

(10) **Patent No.:** **US 9,153,452 B2**
(45) **Date of Patent:** ***Oct. 6, 2015**

(54) **SYSTEMS AND METHODS FOR CHEMICAL MECHANICAL PLANARIZATION WITH PHOTO-CURRENT DETECTION**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 35 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **14/097,400**

(22) Filed: **Dec. 5, 2013**

(65) **Prior Publication Data**

US 2015/0162210 A1 Jun. 11, 2015

(51) **Int. Cl.**

H01L 21/4763	(2006.01)
H01L 21/306	(2006.01)
H01L 21/66	(2006.01)
B24B 37/013	(2012.01)

(52) **U.S. Cl.**

CPC ***H01L 21/30625*** (2013.01); ***B24B 37/013*** (2013.01); ***H01L 22/26*** (2013.01)

(58) **Field of Classification Search**

CPC B24B 1/00

See application file for complete search history.

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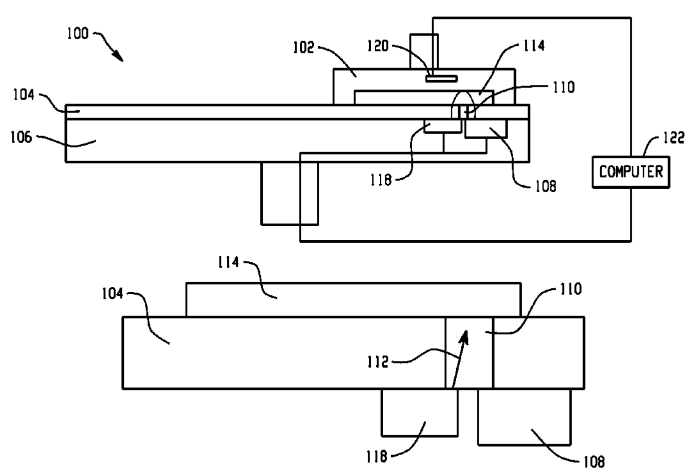
(57) **ABSTRACT**

Systems and methods are provided for performing chemical-mechanical planarization on an article. An example system includes a polishing head, a polishing pad, a light source, a polishing fluid, a current detector, and one or more processors. The polishing head is configured to perform chemical-mechanical planarization (CMP) on an article. The polishing pad is configured to support the article. The light source is configured to emit an incident light. The polishing fluid is configured to perform CMP including a plurality of light-absorption particles being capable of transferring charges to a stop layer in the article in response the incident light. The current detector is configured to detect a current in response to the light-absorption particles transferring charges to the stop layer. The one or more processors are configured to control the polishing head based on the detected current.

22 Claims, 6 Drawing Sheets



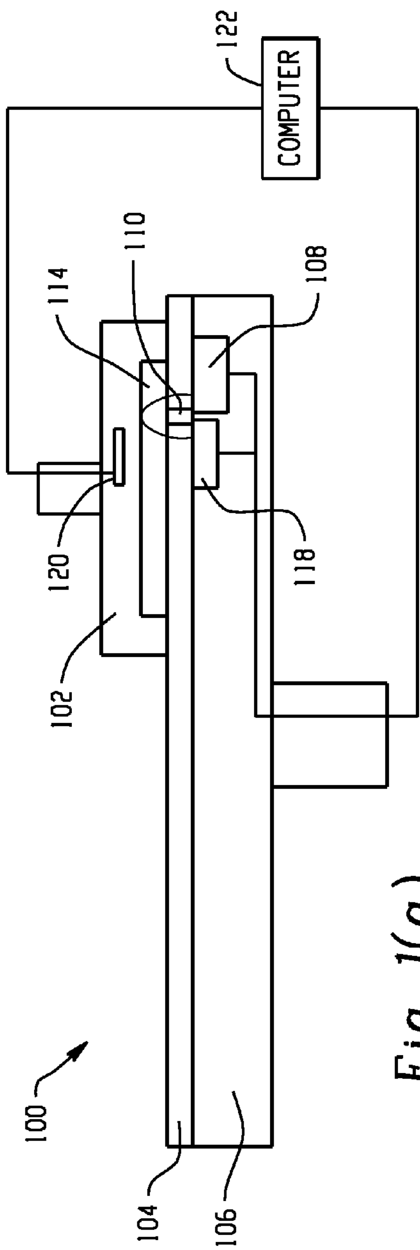
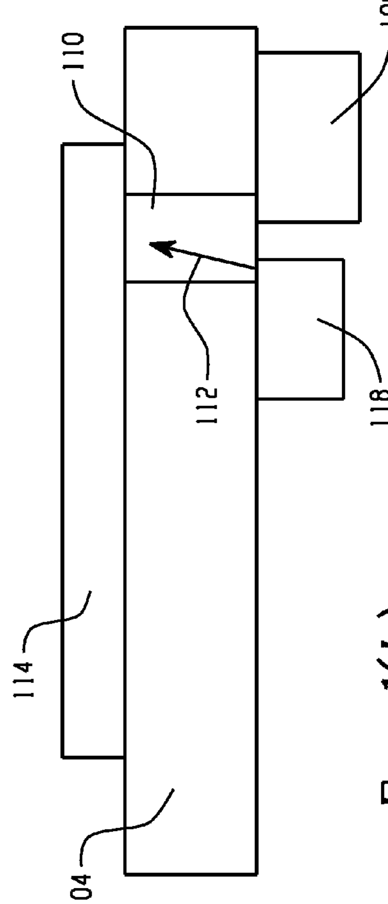

122
COMPUTER
114
110
108
120
118
102
100
104
106

Fig. 1(a)


110
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112
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114
104

Fig. 1(b)

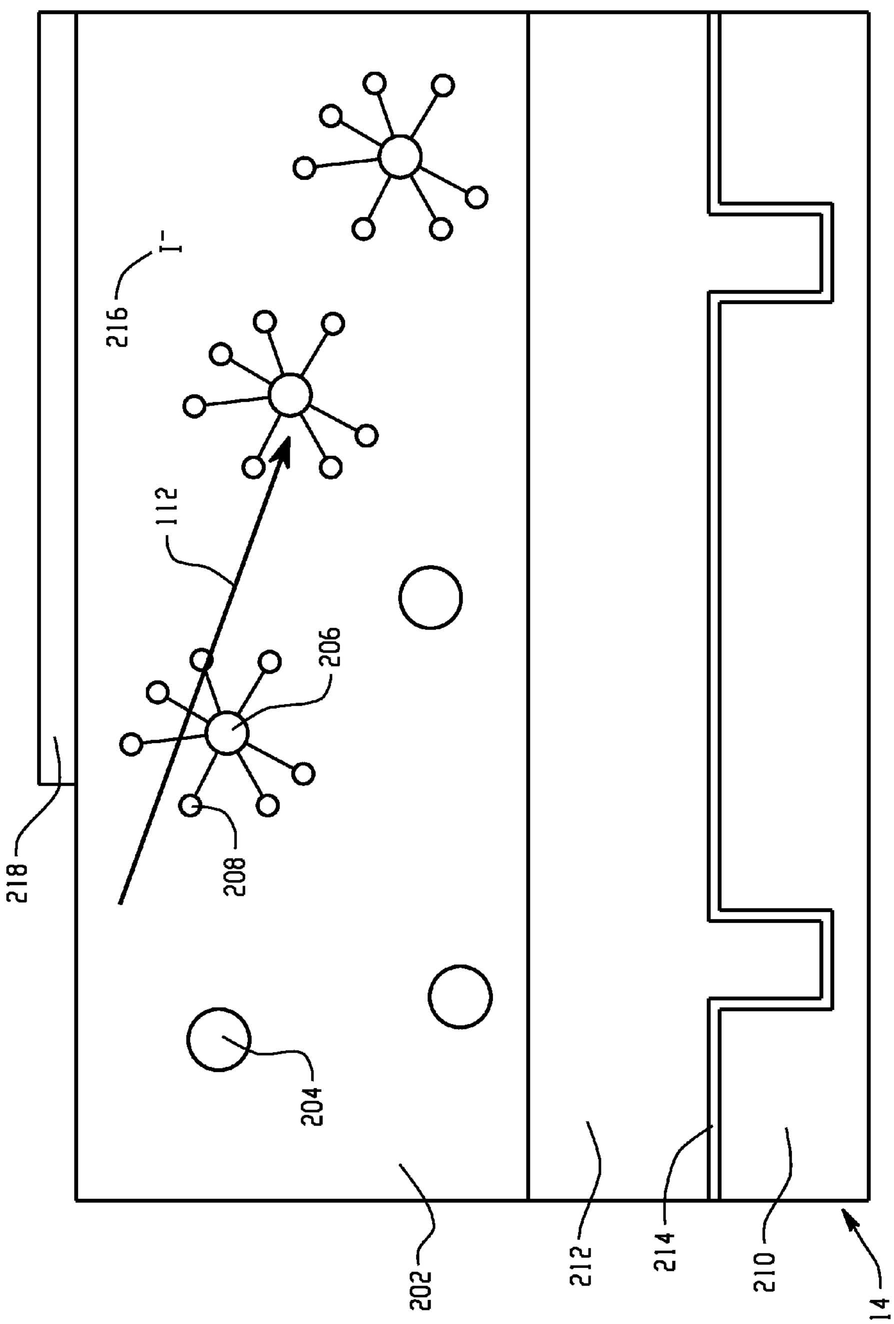

Fig. 2(a)

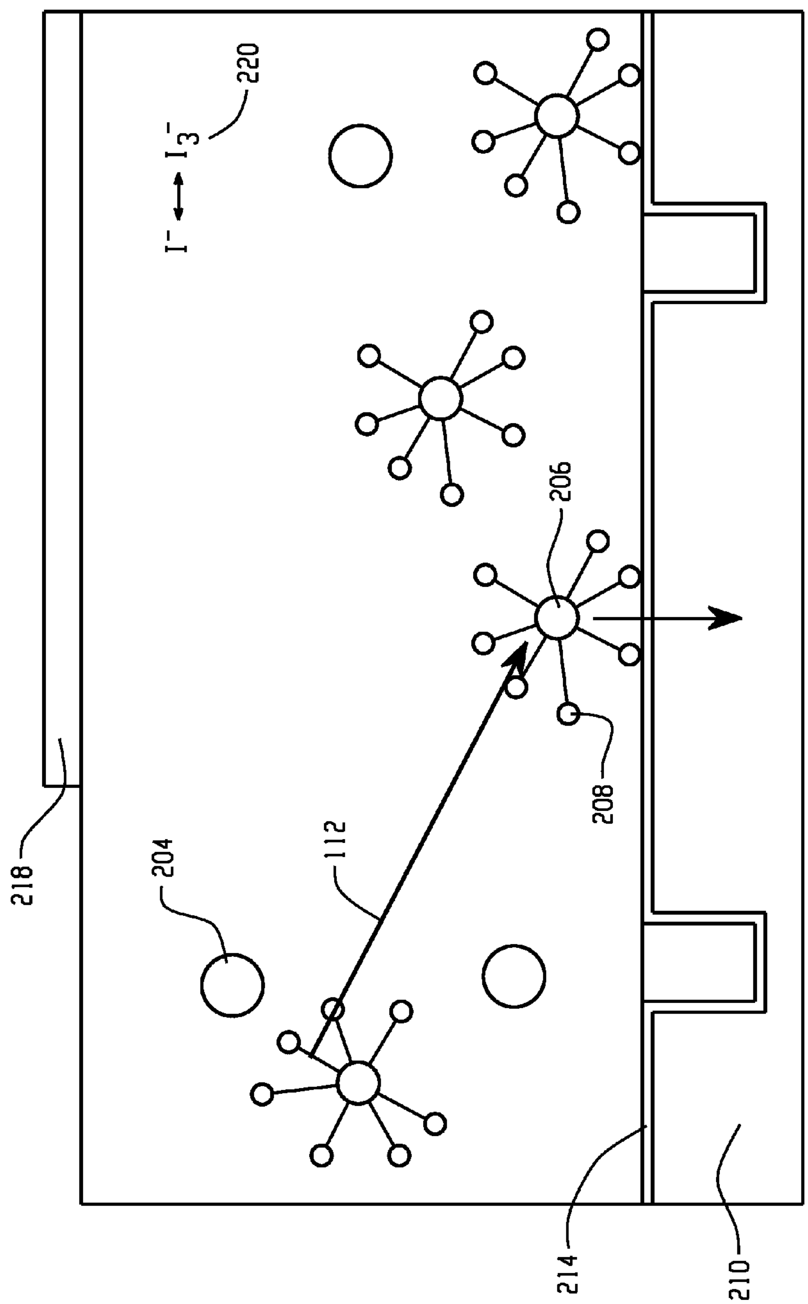

Fig. 2(b)

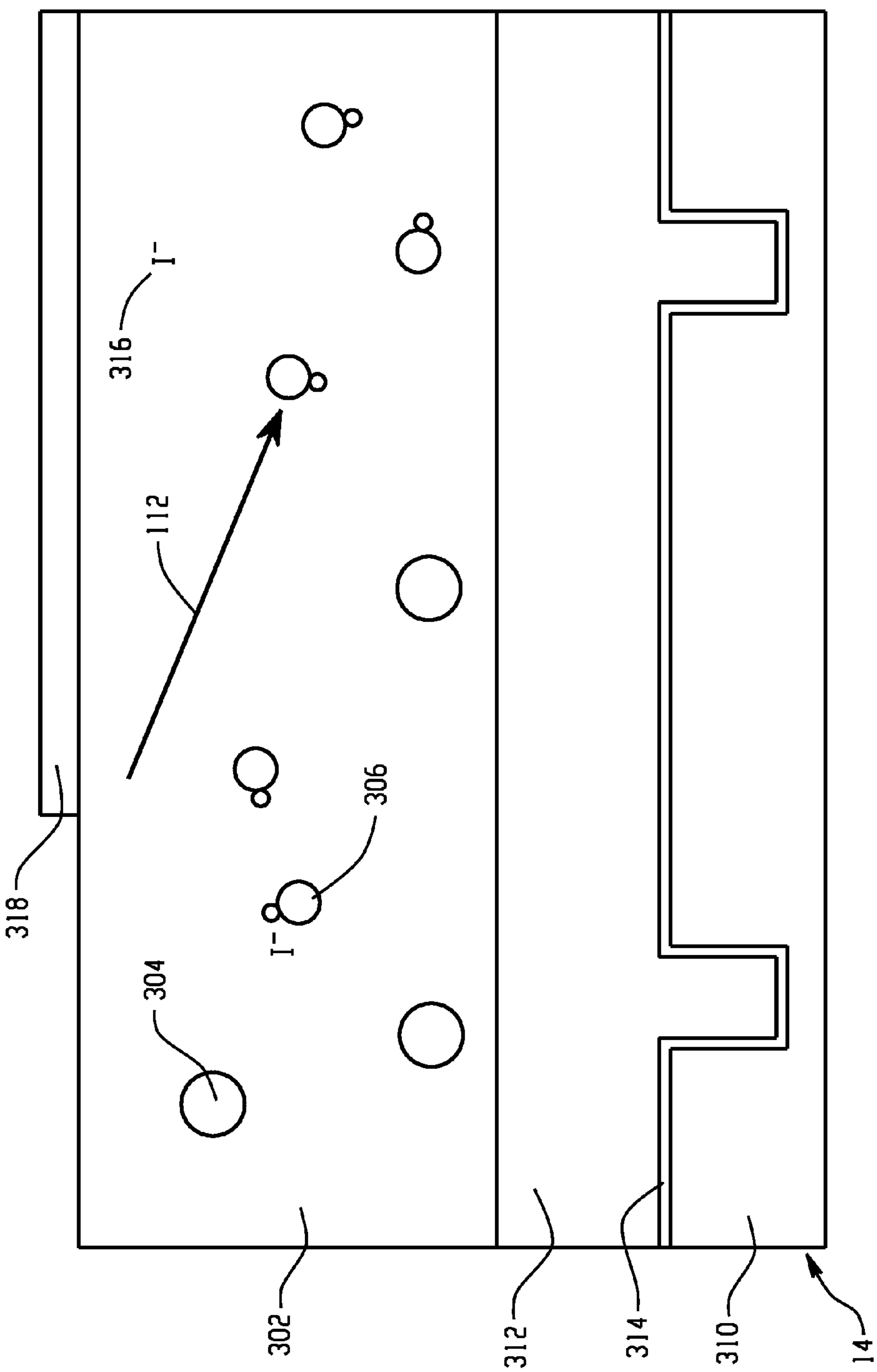

Fig. 3(a)

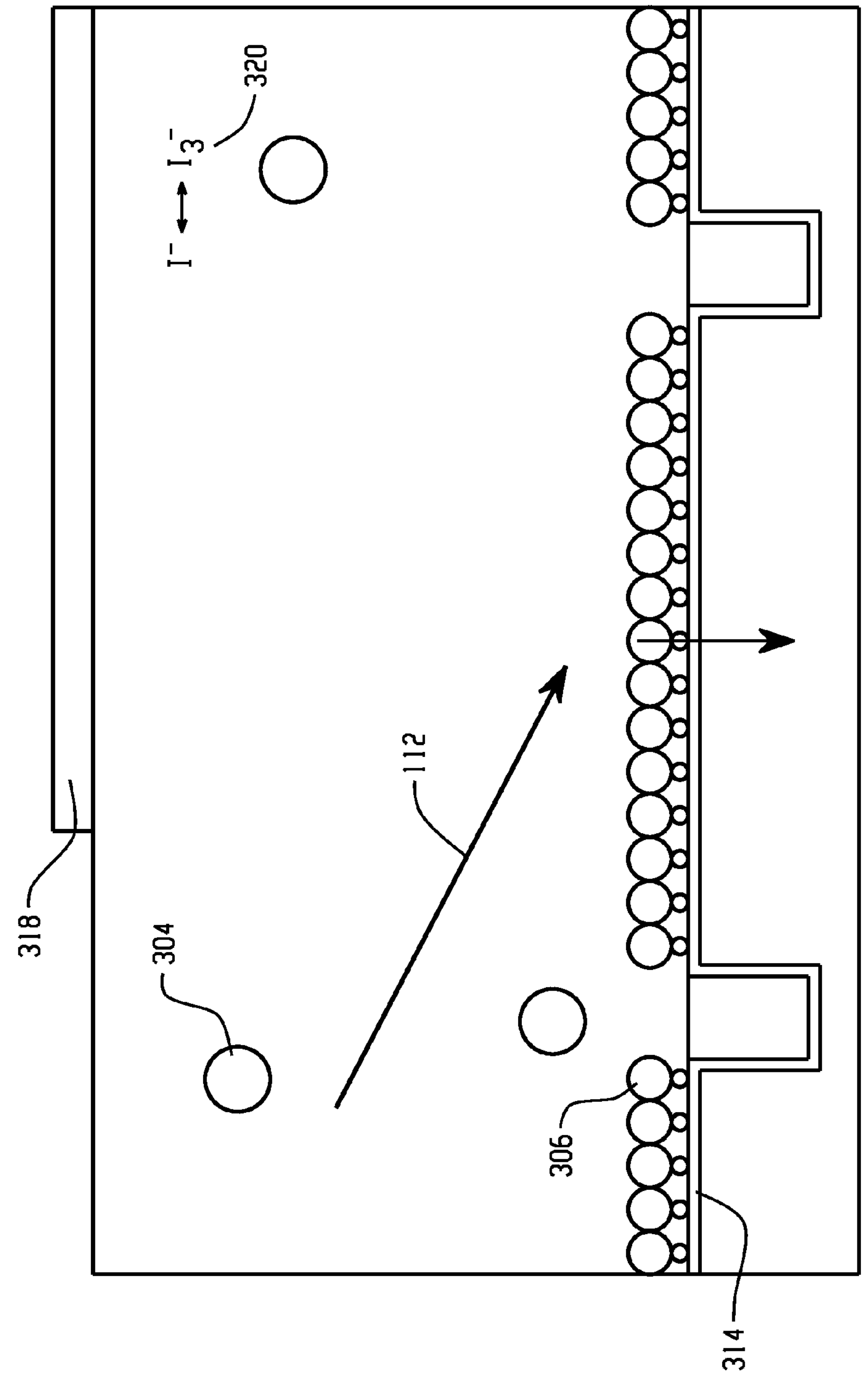

Fig. 3(b)

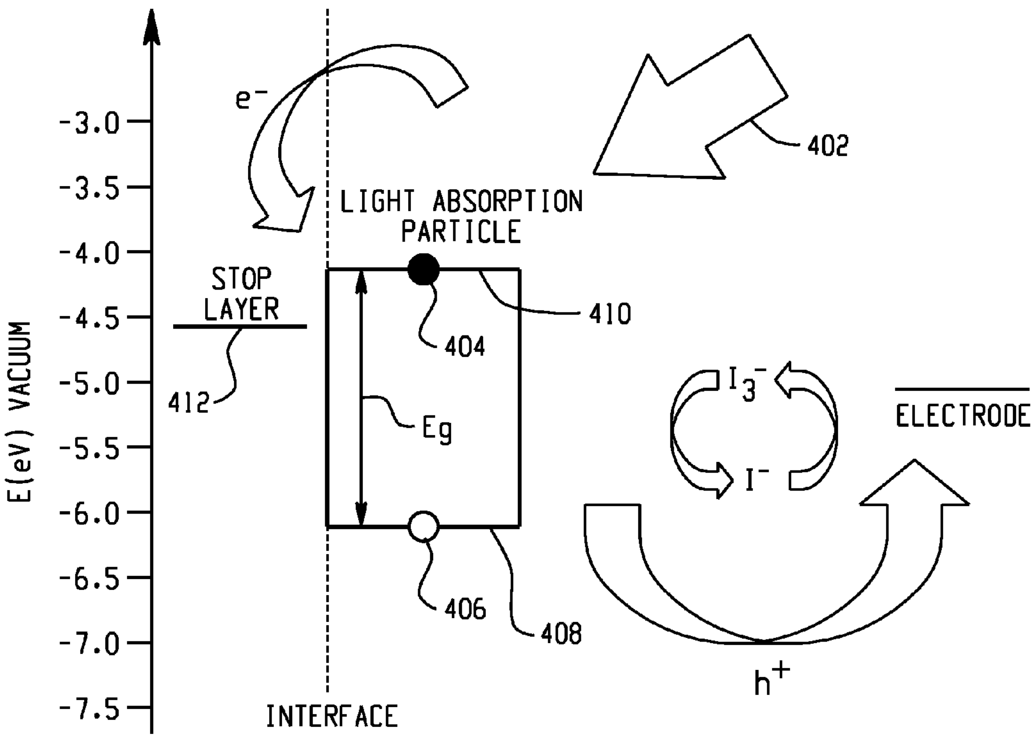
E(eV) VACUUM
-3.0
-3.5
-4.0
-4.5
-5.0
-5.5
-6.0
-6.5
-7.0
-7.5
e⁻
402
LIGHT ABSORPTION PARTICLE
STOP LAYER
410
404
412
Eg
I_3^-
I^-
ELECTRODE
406
408
h^+
INTERFACE

Fig. 4

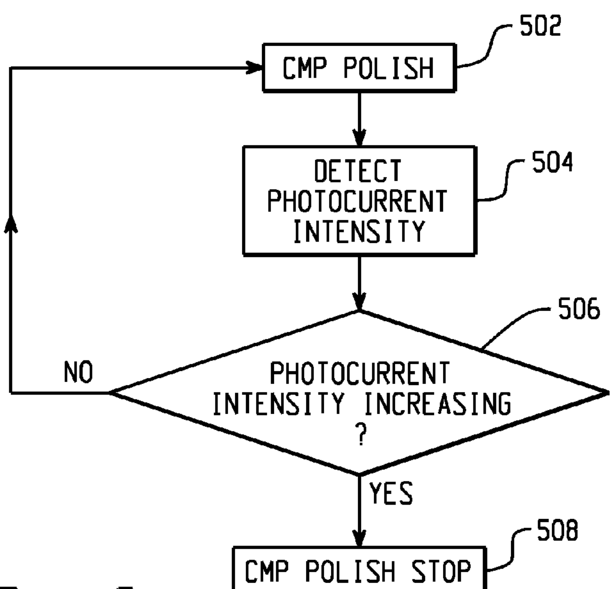
502
CMP POLISH
DETECT PHOTOCURRENT INTENSITY
504
506
NO
PHOTOCURRENT INTENSITY INCREASING ?
YES
508
CMP POLISH STOP

Fig. 5

SYSTEMS AND METHODS FOR CHEMICAL MECHANICAL PLANARIZATION WITH PHOTO-CURRENT DETECTION

FIELD

The technology described in this disclosure relates generally to material processing and more particularly to planarization.

BACKGROUND

Semiconductor devices fabrication involves many processes, such as chemical-mechanical polishing/planarization (CMP) for planarizing surfaces of a wafer. The CMP process implements a combination of chemical and mechanical forces. For example, the CMP process involves both mechanical grinding and wet etching to generate a smooth surface on a wafer for subsequent processes (e.g., photolithography) in the fabrication of semiconductor devices.

SUMMARY

In accordance with the teachings described herein, systems and methods are provided for performing chemical-mechanical planarization on an article. An example system includes a polishing head, a polishing pad, a light source, a polishing fluid, a current detector, and one or more processors. The polishing head is configured to perform chemical-mechanical planarization (CMP) on an article. The polishing pad is configured to support the article. The light source is configured to emit an incident light. The polishing fluid is configured to perform CMP including a plurality of light-absorption particles capable of transferring charges to a stop layer in the article in response the incident light. The current detector is configured to detect a current in response to the light-absorption particles transferring charges to the stop layer. The one or more processors are configured to control the polishing head based on the detected current.

In an embodiment, a method is provided for performing chemical-mechanical planarization on an article. An incident light is provided. Chemical-mechanical planarization (CMP) is performed on an article using a polishing fluid, the polishing fluid including a plurality of light-absorption particles capable of transferring charges to a stop layer in the article in response to the incident light. A current is detected in response to the light-absorption particles transferring charges to the stop layer. In response to the current, the CMP is stopped.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**(*a*)-FIG. **1**(*b*) depict an example diagram showing a CMP system.

FIG. **2**(*a*) and FIG. **2**(*b*) depict an example diagram showing a polishing fluid including light-absorption particles used in the CMP system as shown in FIG. **1**(*a*) and FIG. **1**(*b*).

FIG. **3**(*a*) and FIG. **3**(*b*) depict another example diagram showing a polishing fluid including light-absorption particles used in the CMP system as shown in FIG. **1**(*a*) and FIG. **1**(*b*).

FIG. **4** depicts an example band diagram showing electrons being transferred from a light-absorption particle to a CMP stop layer.

FIG. **5** depicts an example flow chart for performing CMP on an article.

DETAILED DESCRIPTION

Fabrication of semiconductor devices usually includes a CMP process and an etching process. Oftentimes, a thin

nitride layer is used as a CMP stop layer for the CMP process and/or an etching hard mask for the etching process that follows the CMP process. When the CMP stop layer (e.g., titanium nitride, titanium oxide) is exposed, the CMP process is usually supposed to stop. However, it is hard to accurately control the end point of the CMP process. The thin CMP stop layer may be completely removed during the CMP process and layers under the CMP stop layer cannot be protected during the subsequent etching process.

FIG. **1**(*a*)-FIG. **1**(*b*) depict an example diagram showing a CMP system. The CMP system **100** is configured to perform a CMP process with photo-current detection so that the CMP process stops with accuracy when a CMP stop layer (e.g., titanium nitride, titanium oxide) is exposed.

As shown in FIG. **1**(*a*) and FIG. **1**(*b*), the CMP system **100** includes a polishing head **102**, a polishing pad **104**, a platen **106**, and a photo-current detector **108**. A polishing fluid (not shown) used for the CMP process includes light-absorption particles that are capable of transferring charges (e.g., electrons or holes) to a CMP stop layer included in a wafer **114** in response to an incident light **112** (e.g., from a light source **118**). The photo-current detector **108** is configured to detect a photo-current generated as a result of the charge transfer. Upon the detection of the photo-current (e.g., the intensity of the photo-current exceeding a threshold), the CMP process is stopped.

Specifically, one or more small windows **110** in the polishing pad **104** allow the incident light **112** to pass through and fall on the wafer **114** that includes the CMP stop layer (e.g., titanium nitride, titanium oxide). Once the CMP stop layer is exposed during the CMP process, the light-absorption particles begin to transfer charges (e.g., electrons or holes) to the CMP stop layer in response to the incident light **112**. For example, the windows **110** are fabricated using one or more materials that are approximately transparent to the incident light **112**.

The CMP system **100** further includes a polish-head-rotation controller **120** and a computer **122**. For example, the polish-head-rotation controller **120** is configured to control the polishing head **102** to rotate and oscillate to bring the wafer **114** into contact with the polishing pad **104** that moves in the plane of the wafer surface to be planarized (e.g., together with the platen **106**). The computer **122** is configured to control the light source **118** and/or the photo-current detector **108**. As an example, the computer **122** compares the detected intensity of the photo-current with a predetermined threshold, and causes the polish-head-rotation controller **120** to stop the polishing head **102** if the detected current intensity is larger than the predetermined threshold. In certain embodiments, the polishing pad **104** is made of stacks of soft and hard materials (e.g., porous polymeric materials). As an example, the photo-current detector **108** is connected to an electrode in contact with the polishing fluid, as shown in FIG. **2**(*a*) and FIG. **2**(*b*).

FIG. **2**(*a*) and FIG. **2**(*b*) depict an example diagram showing a polishing fluid including light-absorption particles used in the CMP system **100**. The polishing fluid **202** includes an abrasive and corrosive chemical slurry (e.g., a colloid). For example, the polishing fluid **202** includes one or more abrasive materials **204**, and a plurality of light-absorption particles **206** capable of generating charges (e.g., electrons or holes) in response to the incident light **112** and attaching to a CMP stop layer **214** in the wafer **114**. Further, the polishing fluid **202** includes one or more electrolyte particles **216** (e.g., I^- ions) for conducting a current through an electrode **218** which is connected to the photo-current detector **108**. The wafer **114** includes multiple layers on a substrate **210**. One or more material layers **212** (e.g., silicon oxide) are formed on the CMP stop layer **214**. For example, the CMP stop layer **214** includes titanium oxide or titanium nitride.

At the beginning of the CMP process, the CMP stop layer **214** is covered by the material layers **212**, and the light-absorption particles **206** are not attached to the CMP stop layer **214**. For example, the photo-current detector **108** detects no current or a current with low intensity (e.g., below a threshold) through the electrode **218**. As the CMP process continues, the material layers **212** formed on the CMP stop layer **214** are removed, and at least part of the CMP stop layer **214** is exposed. The light-absorption particles **206** begin to attach to the CMP stop layer **214**, as shown in FIG. **2**(*b*). Charges (e.g., electrons or holes) are transferred from the light-absorption particles **206** to the CMP stop layer **214**. The photo-current detector **108** detects a current or an intensity increase of the current, and the CMP process is stopped when the intensity of the current becomes larger than a threshold.

Each of the light-absorption particles **206** includes one or more surfactant particles **208** that can attach to the CMP stop layer **214**. For example, the light-absorption particles **206** include CdS, CdSe, CdTe, ZnO, ZnS, ZnSe, ZnTe, InAs, InN, InP, GaN, GaP, GaAs, AlP, or other suitable materials. The abrasive materials **204** include silica or other suitable materials. The surfactant particles **208** include organic molecules that contain one or more hydroxyl-based (e.g., —OH) functional groups, one or more carboxyl-based (e.g., —COOH) functional groups, one or more ammonium-ion-based (e.g., —NH^+) functional groups, one or more sulfonic-acid-based (e.g., —SO_3H) functional groups, or other suitable functional groups. As an example, the electrolyte particles (e.g., I^- ions) **216** combine to form particles **220** (e.g., I_3^- ions) as a result of the charge transfer between the light-absorption particles **206** and the CMP stop layer **214**.

FIG. **3**(*a*) and FIG. **3**(*b*) depict another example diagram showing a polishing fluid including light-absorption particles used in the CMP system **100**. The polishing fluid **302** includes one or more abrasive materials **304**, and a plurality of light-absorption particles **306** capable of generating charges (e.g., electrons or holes) in response to the incident light **112** and attaching to a CMP stop layer **314** (e.g., titanium oxide, titanium nitride) included in the wafer **114**. Further, the polishing fluid **302** includes one or more electrolyte particles **316** (e.g., I^- ions) for conducting a current through an electrode **318** which is connected to the photo-current detector **108**. In some embodiments, one or more material layers **312** (e.g., silicon oxide) are formed on the CMP stop layer **314**.

During the CMP process, the material layers **312** formed on the CMP stop layer **314** are removed, and at least part of the CMP stop layer **314** is exposed. The light-absorption particles **306** begin to attach to the CMP stop layer **314**, as shown in FIG. **3**(*b*). Charges (e.g., electrons or holes) are transferred from the light-absorption particles **306** to the CMP stop layer **314**. The photo-current detector **108** detects a current or an intensity increase of the current. In some embodiments, when most of the light-absorption particles **306** attach to the surface of the CMP stop layer **314**, the intensity of the detected current increases significantly, and the CMP process is stopped when the intensity of the detected current exceeds a predetermined threshold.

For example, the light-absorption particles **306** include certain dye materials, such as EBFP, Azunite, GFPuv, and T-sapphire. In another example, the light-absorption particles **306** include certain fluorescence conducting polymer materials, such as MEHPPV and P3HT. The light-absorption particles **306** include organic molecules that contain one or more hydroxyl-based (e.g., —OH) functional groups, one or more carboxyl-based (e.g., —COOH) functional groups, one or more ammonium-ion-based (e.g., —NH) functional groups, one or more sulfonic-acid-based (e.g., —SO_3H) functional groups, or other suitable functional groups. The abrasive materials **304** include silica or other suitable materials. As an example, the electrolyte particles (e.g., I^-ions) **316** combine to form particles **320** (e.g., I_3^- ions) as a result of the charge transfer between the light-absorption particles **306** and the CMP stop layer **314**.

FIG. **4** depicts an example band diagram showing electrons being transferred from a light-absorption particle to a CMP stop layer. As shown in FIG. **4**, a light-absorption particle (e.g., the light absorption particles **206** or **306**) contained in a polishing fluid (e.g., the polishing fluid **202** or **302**) is in contact with a CMP stop layer (e.g., the CMP stop layer **214** or **314**). In response to an incident light **402**, one or more electrons **404** of the light-absorption particle are excited from a first energy level **408** to a second energy level **410**, leaving behind one or more holes **406** at the first energy level **408**. The second energy level **410** is higher than an energy level **412** corresponding to a conduction band of the CMP stop layer. The one or more electrons **404** flow from the light-absorption particle to the CMP stop layer, and the one or more holes **406** flow from the light-absorption particle to an electrode (e.g., the electrode **218** or **318**) through one or more electrolyte particles (e.g., I^- ions or I_3^- ions) included in the polishing fluid for photo-current detection.

In some embodiments, the energy of the incident light is larger than a difference between the first energy level **408** and the second energy level **410** which corresponds to a band gap of the light-absorption particle (e.g., Eg). For example, the first energy level **408** is at about −6.0 eV, and the second energy level **410** is at about −4.0 eV. The energy level **412** of the CMP stop layer is at about −4.5 eV. As an example, certain electrolyte particles (e.g., I^-ions) combine to form other electrolyte particles (e.g., I_3^- ions) as a result of the charge transfer between the light-absorption particle and the CMP stop layer.

FIG. **5** depicts an example flow chart for performing CMP on an article. At **502**, the CMP process begins on an article (e.g., a wafer) including a CMP stop layer. A polishing fluid that is used for the CMP process includes a plurality of light-absorption particles capable of generating charges (e.g., electrons or holes) in response to an incident light and attaching to the CMP stop layer included in the article. Once the light-absorption particles attach to the CMP stop layer, the charges (e.g., electrons or holes) transfer from the light-absorption particles to the CMP stop layer. At **504**, a photo-current resulting from the charge transfer from the light-absorption particles to the CMP stop layer is detected. At **506**, a determination whether the intensity of the detected photo-current is increasing (e.g., becoming larger than a threshold) is made. If the intensity of the photo-current is increasing (e.g., becoming larger than a threshold), it indicates that at least a large part of the CMP stop layer is exposed. The CMP process ends to avoid removing the CMP stop layer, at **508**. Otherwise, the CMP process continues.

For example, the light-absorption particles include CdS, CdSe, CdTe, ZnO, ZnS, ZnSe, ZnTe, InAs, InN, InP, GaN, GaP, GaAs, AlP, EBFP, Azunite, GFPuv, T-sapphire, MEH-PPV, P3HT, or other suitable materials. In some embodiments, the light-absorption particles include surfactant particles capable of attaching to the stop layer. As an example, the surfactant particles include organic molecules that contain one or more hydroxyl-based functional groups, one or more carboxyl-based functional groups, one or more ammonium-ion-based functional groups, one or more sulfonic-acid-based functional groups, or other suitable functional groups.

This written description uses examples to disclose embodiments of the disclosure, include the best mode, and also to enable a person of ordinary skill in the art to make and use various embodiments of the disclosure. The patentable scope of the disclosure may include other examples that occur to those of ordinary skill in the art. One of ordinary skill in the relevant art will recognize that the various embodiments may be practiced without one or more of the specific details, or with other replacement and/or additional methods, materials, or components. Further, persons of ordinary skill in the art will recognize various equivalent combinations and substitutions for various components shown in the figures.

Well-known structures, materials, or operations may not be shown or described in detail to avoid obscuring aspects of various embodiments of the disclosure. Various embodiments shown in the figures are illustrative example representations and are not necessarily drawn to scale. Particular features, structures, materials, or characteristics may be combined in any suitable manner in one or more embodiments. The present disclosure may repeat reference numerals and/or letters in the various examples, and this repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various embodiments and/or configurations discussed. Various additional layers and/or structures may be included and/or described features may be omitted in other embodiments. For example, a particular layer described herein may include multiple components which are not necessarily connected physically or electrically. Various operations may be described as multiple discrete operations in turn, in a manner that is most helpful in understanding the disclosure. However, the order of description should not be construed as to imply that these operations are necessarily order dependent. In particular, these operations need not be performed in the order of presentation. Operations described herein may be performed in a different order, in series or in parallel, than the described embodiments. Various additional operations may be performed and/or described. Operations may be omitted in additional embodiments.

This written description and the following claims may include terms, such as top, on, under, etc. that are used for descriptive purposes only and are not to be construed as limiting. The embodiments of a device or article described herein can be manufactured, used, or shipped in a number of positions and orientations. For example, the term "on" as used herein (including in the claims) may not necessarily indicate that a first layer/structure "on" a second layer/structure is directly on or over and in immediate contact with the second layer/structure unless such is specifically stated; there may be one or more third layers/structures between the first layer/structure and the second layer/structure. The term "under" as used herein (including in the claims) may not indicate that a first layer/structure "under" a second layer/structure is directly under and in immediate contact with the second layer/structure unless such is specifically stated; there may be one or more third layers/structures between the first layer/structure and the second layer/structure. The term "substrate" used herein (including in the claims) may refer to any construction comprising one or more semiconductive materials, including, but not limited to, bulk semiconductive materials such as a semiconductive wafer (either alone or in assemblies comprising other materials thereon), and semiconductive material layers (either alone or in assemblies comprising other materials).

What is claimed is:

1. A system for performing chemical-mechanical planarization on an article, comprising:
- a polishing head configured to perform chemical-mechanical planarization (CMP) on an article;
- a polishing pad configured to support the article;
- a light source configured to emit an incident light;
- a polishing fluid configured to perform CMP including a plurality of light-absorption particles capable of transferring charges to a stop layer in the article in response the incident light;
- a current detector configured to detect a current in response to the light-absorption particles transferring charges to the stop layer; and
- one or more processors configured to control the polishing head based on the detected current.

2. The system of claim **1**, wherein:
- the polishing head is configured to perform CMP on the article to expose the stop layer; and
- the light-absorption particles are capable of attaching to the stop layer to transfer the charges to the stop layer.

3. The system of claim **2**, wherein the polishing head is configured to stop the chemical-mechanical planarization in response to the current detector detecting the current.

4. The system of claim **1**, wherein:
- the light-absorption particles are capable of absorbing the incident light to excite one or more electrons from a first energy level to a second energy level; and
- the one or more electrons excited to the second energy level are capable of being transferred to a third energy level corresponding to a conduction band of the stop layer.

5. The system of claim **4**, wherein the current detector is further configured to receive one or more holes generated as a result of the one or more electrons being excited from the first energy level to the second energy level.

6. The system of claim **5**, wherein the current detector is connected to an electrode in contact with the polishing fluid.

7. The system of claim **5**, wherein the polishing fluid further includes a plurality of electrolyte particles configured to transfer the one or more holes from the light-absorption particles to the current detector.

8. The system of claim **4**, wherein a difference between the first energy level and the second energy level corresponds to a band gap associated with the light-absorption particles.

9. The system of claim **4**, wherein energy of the incident light is larger than a difference between the first energy level and the second energy level.

10. The system of claim **1**, wherein the stop layer includes titanium nitride or titanium oxide.

11. The system of claim **1**, wherein the light-absorption particles include at least one of CdS, CdSe, CdTe, ZnO, ZnS, ZnSe, ZnTe, InAs, InN, InP, GaN, GaP, GaAs, AlP, EBFP, Azunite, GFPuv, T-sapphire, MEHPPV, and P3HT.

12. The system of claim **1**, wherein a light-absorption particle includes one or more surfactant particles capable of attaching to the stop layer.

13. The system of claim **12**, wherein the surfactant particles include organic molecules that contain one or more hydroxyl-based functional groups, one or more carboxyl-based functional groups, one or more ammonium-ion-based functional groups, or one or more sulfonic-acid-based functional groups.

14. The system of claim **1**, wherein the polishing fluid further includes one or more abrasive materials.

15. The system of claim **1**, wherein the polishing pad includes one or more areas for the incident light to pass through.

16. The system of claim **15**, wherein the one or more areas are fabricated using one or more particular materials approximately transparent to the incident light.

17. A method for performing chemical-mechanical planarization on an article, the method comprising:

providing an incident light;

performing chemical-mechanical planarization (CMP) on an article using a polishing fluid, the polishing fluid including a plurality of light-absorption particles capable of transferring charges to a stop layer in the article in response to the incident light;

detecting a current in response to the light-absorption particles transferring charges to the stop layer; and

in response to the current, stopping the CMP.

18. The method of claim **17**, wherein the stop layer includes titanium nitride or titanium oxide.

19. The method of claim **17**, wherein the light-absorption particles include at least one of CdS, CdSe, CdTe, ZnO, ZnS, ZnSe, ZnTe, InAs, InN, InP, GaN, GaP, GaAs, AlP, EBFP, Azunite, GFPuv, T-sapphire, MEHPPV, and P3HT.

20. The method of claim **17**, wherein:

a light-absorption particle includes one or more surfactant particles capable of attaching to the stop layer; and

the surfactant particles include organic molecules that contain one or more hydroxyl-based functional groups, one or more carboxyl-based functional groups, one or more ammonium-ion-based functional groups, or one or more sulfonic-acid-based functional groups.

21. The method of claim **17**, wherein:

the light-absorption particles absorb the incident light to excite one or more electrons from a first energy level to a second energy level; and

the one or more electrons excited to the second energy level are transferred to a third energy level corresponding to a conduction band of the stop layer.

22. A system for performing chemical-mechanical planarization on an article, comprising:

one or more processors; and

a non-transitory computer readable storage medium comprising programming instructions, the programming instructions configured to cause one or more processors to execute operations comprising:

providing an incident light;

performing chemical-mechanical planarization (CMP) on an article using a polishing fluid, the polishing fluid including a plurality of light-absorption particles capable of transferring charges to a stop layer in the article in response to the incident light;

detecting a current in response to the light-absorption particles transferring charges to the stop layer; and

in response to the current, stopping the CMP.

* * * * *